10E. These component circuits are shown separately as Figures 10A through 10E, corresponding to the breakout shown in Figure 10.

[0092] At the heart of the proximity detector is an adjustable asymmetric rectangular wave oscillator running in a range of 24 kHz to 40kHz, as shown in Figure 10A. Once an initial adjustment has been set it is not readjusted during operation, normally. The asymmetrical feature of having a longer on-time and shorter off-time allows for more useable signal, i.e., on-time. This 24 kHz to 40kHz oscillation range provides a basis for a high rate of sampling of the environment to detect capacitance changes, as detailed below. As shown, a fast comparator, XU2A **200**, has positive feedback through XR18 **202** from the output terminal 1 **204** (XU2A) to the positive input terminal 3 **206** (XU2A). The comparator operates as a Schmitt trigger oscillator with positive feedback to the non-inverting input, terminal. The positive feedback insures a rapid output transition, regardless of the speed of the input waveform. As the capacitor XC6 **208** is charged up, the terminal 3 **206** of the XU2A **200** comparator reaches 2/3 XV_{DD}. This voltage 2/3 XV_{DD} is maintained on terminal 3 **206** by the voltage dividing network XR17 **212** and XR20 **214**, and the positive feedback resistor XR18 **202** that is in parallel with XR17 **212**, where XR17 **212** and XR20 **214** and XR18 **202** are all equal resistances. The simplest form of a comparator is a high-gain differential amplifier, made either with transistors or with an op-amp. The op-amp goes into positive or negative saturation according to the difference of the input voltages because the voltage gain is typically larger than 100,000, the inputs will have to be equal to within a fraction of a millivolt in order for the output not to be completely saturated. Although an ordinary op-amp can be used as comparator, there are special integrated circuits intended for this use. For low power consumption, better performance is achieved with a CMOS comparator, such as a TEXAS INSTRUMENT ® TLC3702CD ® **158** (Figure 8B). The TLC 3702 **158** is a micropower dual comparator with CMOS push-pull **156** (Figure 8B) outputs. These dedicated comparators are much faster than the ordinary op-amps.

[0001] As the transition occurs, the output, at the output terminal 1 **204,** goes relatively negative, XD5 **216** is then in a forward conducting state, and the capacitor XC6 **208** is preferentially discharged through the resistance XR15 **218** (100kΩ) and the diode XD5 **216**.

[0094] The time constant for charging the capacitor XC6 **206** is determined by resistors XVR1 **220**, XR13 **222** and XR15 **218**. The resistor XR15 **218**

and the diode XD5 **216** determine the time constant for discharge of the capacitor XC6 **208**.

[0095] The reset time is fixed at 9 μs by XD5 **216** and XR15 **218**. The rectangular wave source supplying the exponential to the antenna, however, can be varied from 16 to 32 μs, utilizing the variable resistance XVR1 **220** and the resistors XR13 **222** and XR15 **218**. Once set up for operational the variable resistance is not changed. The asymmetric oscillator can produce more signal (16 μs to 32 μs, as compared to the reset time. The reset time is not especially important, but the reset level is both crucial and consistent. The exponential waveform always begins one "diode voltage drop" (vbe) above the negative rail due to the forward biased diode voltage drop of XD2 **224** (Figure 10B). One "diode voltage drop" (vbe) is typically in the range 0.5 V to 0.8 V, or typically about 0.6 V.

[0096] The dual diode XD4 **226** (Figure 10A) provides protection from static electricity. Terminal 1 **228** of XD4 **226** will conduct when terminal 3 **230** is at least one diode voltage drop below the ground, or negative rail. Terminal 2 **232** will conduct when terminal 3 **230** is at least one diode voltage drop above V_{DD} **234**. Therefore, the signal level at terminal 3 **230** is limited to the range –vbe to VDD + vbe, thereby eliminating voltage spikes characteristic of "static", which may be induced by lightening or the operation of electrical motors, for example. The static is primarily built up by the internal mechanisms of the towel dispenser and the movement of the paper and is discharged by bringing a waving hand near the sensor.

[0001] The asymmetric square wave charges the antenna **236** (Figure 10B) through the resistors XR9 **238** and XR4 **240**. The sum resistance, XR, is equal to XR9 **238** plus XR4 **240**, or 1.7 MΩ, for the example values shown in Figures 10 and 10B. The antenna **236** forms one conducting side of a capacitor, while the atmosphere and other materials form a dielectric between the antenna as one conducting element and other conductive materials including buildings and the actual earth as a second conductive element. The capacitance C of the antenna **236** relative to "free space" is approximately 7 pF to 8 pF, as determined by experiment, yielding a time constant τ, where τ is equal to RC. Thus, the time constant, for the exemplary values, is about 13 μs.

[0098] If a hand of a person is placed in proximity to the antenna of the circuit, the capacitance of the antenna to free space may double to about 15 pF with a resultant longer time constant and lower amplitude exponential waveform. The time

constant τ is increased to about 26 μs. While it is possible to directly compare the signals, it is also desirable to have as stable an operating circuit as possible while retaining a high sensitivity and minimizing false positives and false negatives with respect to detection. To aid in achieving these goals, the signal is conditioned or processed first.

[0001] Looking at the operational amplifier XU1A **242**, the (signal) waveform sees very high impedance, since operational amplifiers have high input impedance. The impedance on the antenna **236** side of the operational amplifier **242**, in the form of resistance, is about 1.9 MΩ. The impedance on the other side of the operational amplifier is of the order of 5 kΩ. In order to provide an impedance buffer the signal the operational amplifier UX1A **242** is set up as a unity follower with a voltage gain of 1.0, that is, the gain given by V_{out}/V_{in} equals one. The unity follower has an input-side (of the operational amplifier) resistance of about 1.0 TΩ (10^{13} Ω). The (operational amplifier's) output impedance is in a range about 40 to 600 to several thousand ohms. Consequently, this unity follower configuration serves to isolate or buffer the upstream high-impedance circuit from the downstream low impedance circuit.

[0100] The resistor XR2 **244** acts as a current limiter, since the current i is equal to v/XR2 at XR2 **244**. Further protection against static is provided by the diode pair XD3 **246** in the same way as diode pair XD4 **226** (Figure 10A). Terminal 1 **248** of XD3 **246** will conduct when terminal 3 **250** is at least one diode voltage drop below the ground, or negative rail. Terminal 2 **252** will conduct when terminal 3 **250** is at least one diode voltage drop above V_{DD}. Therefore, the signal level at terminal 3 **250** is limited to the range –vbe to V_{DD} + vbe, so that voltage spikes characteristic of "static" are eliminated.

[0101] Asymmetric oscillator pulses, after detecting capacitance which either includes or does not include a proximate dielectric equivalent to that of a proximate hand, act on the positive (non-inverting) input terminal **254** of the unity follower operational amplifier **242** to produce a linear output at its output terminal **256**. The state of the output terminal is determined by first, the length of the asymmetric on pulse, and within the time of the "on" pulse, the time taken to charge up the antenna **236** (as capacitor) and the time to discharge through XR2 **244** to the non-inverting input terminal **254**. The time-constant–to-charge is 13 μs to 26 μs. The